(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 996 216 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
18.02.2004 Bulletin 2004/08

(51) Int Cl.[7]: **H02K 21/14**

(21) Application number: **99402202.8**

(22) Date of filing: **07.09.1999**

(54) **Permanent magnet motor and rotor thereof**

Dauermagnetmotor und dessen Rotor

Moteur à aimants permanents et rotor pour ledit moteur

(84) Designated Contracting States:
DE FR GB

(30) Priority: **30.09.1998 JP 27760398**
30.09.1998 JP 27763598
30.09.1998 JP 27842198

(43) Date of publication of application:
26.04.2000 Bulletin 2000/17

(73) Proprietor: **SHIN-ETSU CHEMICAL CO., LTD.**
Chiyoda-ku Tokyo (JP)

(72) Inventors:
- **Sato, Koji**
  Takefu-shi, Fukui-ken (JP)
- **Minowa, Takehisa**
  Takefu-shi, Fukui-ken (JP)
- **Miyata, Koji**
  Takefu-shi, Fukui-ken (JP)

(74) Representative: **Armengaud Ainé, Alain et al**
Cabinet ARMENGAUD AINE
3 Avenue Bugeaud
75116 Paris (FR)

(56) References cited:
EP-A- 0 801 459
US-A- 3 770 998
US-A- 4 012 652
US-A- 4 052 630
US-A- 4 695 419
US-A- 4 701 656
US-A- 5 323 077
US-A- 5 604 390

EP 0 996 216 B1

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a multipolar-magnetized cylindrical permanent magnet as a rotor of a permanent magnet motor or a synchronous motor such as servomotors and spindle motors and a permanent magnet motor assembled by using the rotor. More particularly, the invention relates to a multipolar-magnetized cylindrical permanent magnet having magnetic anisotropy in a single diametral direction or in a single direction perpendicular to the axis of the cylindrical magnet body as well as a permanent magnet motor using the same as the rotor.

[0002] As is well known, permanent magnets having magnetic anisotropy or, namely, permanent magnets capable of being more easily magnetized in a specific direction than in the other directions are widely employed as a part of loudspeakers, electric motors, metering instruments and other electric apparatuses. Such a magnetically anisotropic permanent magnet is prepared from a permanent magnet material having crystalline magnetic anisotropy such as certain hard ferrites and rare earth element-containing alloys as the starting material which is pulverized into a powder of fine particles followed by compression molding of the powder within a magnetic field, referred to as in-field molding hereinafter, to give a powder compact and then sintering the powder compact. In the in-field compression molding of the magnetic powder, the magnetic particles are each oriented relative to the easy magnetization axis of the magnet crystallites as a consequence of the magnetic field applied so that the resultant sintered magnet also has magnetic anisotropy in the direction of the magnetic field applied to the powder under compression in the in-field molding.

[0003] The direction of the magnetic field in the in-field molding of magnetically anisotropic magnetic particles can be either perpendicular or parallel to the direction of compression for molding. For example, the anisotropic direction, i.e. the most easily magnetizable direction, of a cylindrical permanent magnet prepared from a powder of a rare earth-based magnetic alloy can be either in parallel to the axial direction of the cylindrical form or in a radial direction perpendicular to the cylinder axis. Cylindrical rare earth permanent magnets having a radial anisotropic direction are employed as a rotor in various types of permanent magnet motors such as AC servomotors, DC brushless motors and the like because of the advantages that they can be freely magnetized in the axial direction and no reinforcement means is required for assembling unit magnets as in the assemblage of segment magnets. In recent years, furthermore, a radially anisotropic cylindrical permanent magnet having an increased height or dimension in the axial direction is required to be in compliance with the expansion of the application fields of permanent magnet motors.

[0004] A cylindrical permanent magnet having radial anisotropy is prepared usually by the method of in-field compression molding or by the method of backward extrusion molding of the magnet powder. In the in-field compression molding method, while it is usual that the magnetic alloy powder in a metal mold is compressed in the axial direction of the cylinder, a magnetic field is applied to the powder under compression in radial direction through cores at each of the opposite ends of cylindrical diameters. Accordingly, the height, i.e. the dimension in the axial directions of the cylinder, of a radially anisotropic cylindrical magnet is limited by the dimensions or shape of the cores so that a radially anisotropic cylindrical magnet of an increased height can be prepared only with great difficulties. This method is also not productive because only one molded body can be obtained in a single shot of molding using a single molding press. The method of backward extrusion molding is also disadvantageous due to the high cost for the preparation of molded bodies because the method requires a large and complicated, and hence very expensive, molding machine and the yield of acceptable molded bodies is relatively low. This situation naturally leads to expensiveness of permanent magnet motors using an expensive multiradially anisotropic cylindrical permanent magnet as the rotor.

[0005] Even without using a multiradially anisotropic cylindrical permanent magnet, a high-performance cylindrical magnet as a rotor in a permanent magnet motor could be obtained when multipolar magnetization of a cylindrical permanent magnet could be accomplished with a sufficiently high magnetic flux density on the surface and with little variation in the magnetic flux densities among the magnetic poles. In this regard, a method is proposed in the papers of Electricity Society, Magnetics Group MAG-85-120 (1985), according to which a cylindrical magnet having magnetic orientation in a single direction perpendicular to the cylinder axis prepared by using an in-field molding press under application of a magnetic field in the direction perpendicular to the direction of compression, referred to as a diametrally oriented cylindrical permanent magnet hereinafter, is magnetized in multipolar magnetization so that a multipolar cylindrical permanent magnet to serve as a rotor in a permanent magnet motor can be obtained without using an expensive multiradially anisotropic magnet.

[0006] The above mentioned cylindrical permanent magnet magnetically oriented in a single direction perpendicular to the cylinder axis, referred to as a diametrally oriented cylindrical magnet, may have an increased heigh of 50 mm or even larger if permitted by the dimensions of the cavity of the metal mold and multi-stage molding method can be undertaken so that a plurality of diametrally oriented cylindrical magnets can be obtained by a single shot of compression molding using a multi-cavity metal mold at low costs. Such a diametrally oriented multipolar cylindrical permanent magnet can be employed in place of expensive multi-radially anisotropic magnets as a rotor in permanent magnet motors.

[0007] Though possible in principle, the above mentioned diametrally oriented cylindrical permanent magnets are practically infeasible as a rotor of a permanent magnet motor due to the irregular distribution of magnetic flux density around the circumferential surface of the cylindrical permanent magnet in such a way that the magnetic flux density is high on the magnetic pole at or in the vicinity of the direction of the diametral orientation axis and low on the magnetic pole at or in the vicinity of the direction perpendicular to the diametral orientation axis so that the rotational torque of the motor constructed with the rotor is necessarily uneven around the rotation axis corresponding to the uneven distribution of the magnetic flux density.

[0008] For example, patent US 4 012 652 discloses a unidirectional self starting synchronous motor comprises a stator having pole teeth of alternating polarity, the total number of effective poles equals the theoretical synchronous number and these are poles divided substantially evenly between the groups and a rotor it could have from radially-polarized anisotropic ferrite.

SUMMARY OF THE INVENTION

[0009] The present invention accordingly has a primary object to provide a permanent magnet motor having a diametrally oriented cylindrical permanent magnet as the rotor without the above described problems and disadvantages in the conventional permanent magnet motors of similar types. The unexpected discovery leading to the present invention in this regard is that a righ-performance permanent magnet motor with a diametrally oriented cylindrical permanent magnet as the rotor can be obtained when the number of the magnetic poles of the multipolar-magnetized cylindrical permanent magnet rotor and the number of the stator teeth of the stator satisfy a certain specific relationship.

[0010] A secondary object of the invention is to provide a novel and improved diametrally oriented cylindrical permanent magnet rotor having an increased height in the axial direction to be freed from the limitation in the height of a diametrally oriented cylindrical permanent magnet rotor.

[0011] Thus, the permanent magnet motor provided by the invention to accomplish the above described primary object of the present invention is an assembly which comprises:

(a) a stator having a plurality of stator teeth; and
(b) a rotor coaxially inserted into the stator, which is a monolithic cylindrical permanent magnet having magnetic anisotropy in a single diametral direction perpendicular to the cylinder axis and magnetized to have a plurality of evenly disposed magnetic poles around the circumference of the cylinder,

in which the number of the magnetic poles k of the rotor is an even number not exceeding 100 and the number of the stator teeth n is equal to $3n_0$, n_0 being a positive integer not exceeding 33, with the proviso that k is not equal to n.

[0012] In a particular embodiment of the above defined permanent magnet motor, the diametrally oriented cylindrical permanent magnet as the rotor is magnetized in multipolar skew magnetization, in which the skew angle of the multipolar skewed magnetic poles is in the range from one tenth to two thirds of 360°/k.

[0013] In a further particular embodiment of the permanent magnet motor, the stator has a plurality of skewed stator teeth, in which the skew angle of the skewed stator teeth is in the range from one tenth to two thirds of 360°/k.

[0014] The above defined relationship between the number of the multipolar magnetic poles k of the rotor and the number of the stator teeth n of the stator can be defined in a different way that the number of the magnetic poles k is an even number not smaller than 4 and the number of the stator teeth n is equal to $3k \cdot n_0/2$, n_0 being a positive integer.

[0015] The present invention further provides, in order to accomplish the secondary object of the invention, a rotor in a permanent magnet motor in the form of a composite cylindrical permanent magnet block, which comprises at least one assembly of at least two or, preferably, two to ten cylindrical unit permanent magnets coaxially stacked one on the other each having magnetic anisotropy in a single diametral direction perpendicular to the cylinder axis, the composite cylindrical permanent magnet block being magnetized in multipolar magnetization to have a plurality of magnetic poles around the circumference of the cylindrical block.

[0016] In a particular embodiment of the above defined rotor for a permanent magnet motor, the direction of diametral orientation of a first cylindrical unit permanent magnet makes a rotational displacement angle within a plane perpendicular to the cylinder axis relative to the direction of diametral orientation of a second cylindrical unit permanent magnet adjacent to the first cylindrical unit permanent magnet, the angle being equal to 180° divided by the number of the cylindrical unit permanent magnets stacked together one on the other, assuming that the cylindrical unit permanent magnets each have an identical height with the others.

[0017] In a further particular embodiment of the above defined rotor, the number of the magnetic poles around the circumference of the composite cylindrical permanent magnet block is an even number not exceeding 50 and the number of the cylindrical unit permanent magnets coaxially stacked together one on the other is equal to one half of the number of the magnetic poles.

[0018] In a still particular embodiment of the above defined rotor, the composite cylindrical permanent magnet block

is magnetized to have a plurality of skewed magnetic poles around the circumference of the cylinder, in which the skew angle of the skewed magnetic poles is in the range from one tenth to two thirds of 360° divided by the number of the skewed magnetic poles.

BRIEF DESCRIPTION OF THE DRAWING

[0019]

Figures 1A and 1B are each a schematic plan view of a diametrally oriented cylindrical permanent magnet as a rotor of a permanent magnet motor under six-polar magnetization in a magnetizer head with the direction of diametral orientation in parallel or perpendicular, respectively, to the direction connecting a pair of energizing coils of the magnetizer head.

Figure 2 is a graph showing distribution of the magnetic flux density on the circumferential surface of a diametrally oriented cylindrical permanent magnet magnetized in six-polar magnetization.

Figure 3 is a schematic plan view of a three-phase permanent magnet motor built in Example 1 consisting of a rotor of a six-polar magnetized diametrally oriented cylindrical permanent magnet and a stator with nine stator teeth.

Figure 4 is a graph showing the induced voltage in the three-phase permanent magnet motor built in Example 3 rotating at 1000 rpm as a function of the electrical angle.

Figure 5 is a schematic plan view of a three-phase permanent magnet motor built in Example 6 with a ten-polar magnetized diametrally oriented permanent magnet as the rotor and a stator having twelve stator teeth.

Figure 6 is a perspective view of a multi-stage composite rotor consisting of three diametrally oriented cylindrical unit permanent magnets coaxially stacked together one on the other in such a disposition that the direction of diametral orientation of one unit magnet makes an angle of 60° with the adjacent unit magnet.

Figure 7 is a graph showing the induced voltage in the three-phase permanent magnet motor built in Example 13 rotating at 1000 rpm as a function of the electrical angle.

Figure 8 is a perspective view of a multi-stage composite rotor consisting of six diametrally oriented cylindrical unit permanent magnets coaxially stacked together one on the other in such a disposition that the direction of diametral orientation of one unit magnet makes an angle of 120° with the adjacent unit magnet.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] In the following, the various embodiments of the present invention are described in detail by way of examples making reference to the accompanying drawing. Although the following description is given solely for the cases where the cylindrical permanent magnet having magnetic anisotropy in a single diametral direction is a neodymium/iron/boron-based permanent magnet which belongs to a most promising class of rare earth-based permanent magnets, the scope of the present invention is never limited to such a specific class of magnets but the principles of the present invention are applicable to any classes of permanent magnets provided that the magnet is made from a magnetic alloy having crystalline magnetic anisotropy.

[0021] Figure 1A of the accompanying drawing is a schematic plan view of a diametrally oriented cylindrical or ring-formed permanent magnet 1 under six-polar magnetization in a magnetizer head 10. The direction of orientation of the diametrally oriented permanent magnet 1 is indicated by the double-sided arrow. The magnetizer head 10 has six magnetic pole teeth 11,11 and six energizing coils 12,12 by means of which the diametrally oriented cylindrical magnet 1 is six-polar magnetized to have three N-poles and three S-poles as if the cylindrical magnet be an assembly of six imaginary sector magnets A, B, C, D, E and F.

[0022] Figure 2 is a graph showing distribution of the magnetic flux density on and around the circumferential surface of a diametrally oriented cylindrical permanent magnet 1 of a neodymium/iron/boron alloy magnetized by using the magnetizer head 10 illustrated in Figure 1A to have evenly disposed six magnetic poles. This graph was obtained by measuring the magnetic flux density on and around the circumferential surface of the cylindrical permanent magnet 1 starting from the imaginary sector A and going around the imaginary sectors B, C, D, E and F in this order.

[0023] As is shown in Figure 2, the curve has maximum points corresponding to the respective imaginary sectors A to F but the maximum values of magnetic flux density for the imaginary sectors B, C, E and F adjacent to or in the vicinity of the direction of the diametral orientation of the cylindrical magnet 1 indicated by the double-sided arrow in Figure 1A are each much larger than the maximum values for the imaginary sectors A and D remote from the direction of the diametral orientation of the magnet 1. In addition, furthermore, the peaks B, C, E and F each have a much larger breadth than the peaks A and D notwithstanding the use of a magnetizer head having evenly disposed energizing coils 12,12 and hence giving an evenly distributed magnetizing field. Namely, the diametrally oriented cylindrical permanent magnet 1 magnetized in six-polar magnetization has six magnetic poles consisting of four poles B, C, E and F each giving a large overall magnetic flux and two poles A and D each giving a small overall magnetic flux. Needless to say,

such unevenness in the distribution of magnetic flux density around the cylindrical permanent magnet 1 used as a rotor in a permanent magnet motor results in unevenness of the rotation torque on the shaft of the motor not to ensure smooth rotation of the motor shaft.

[0024] Figure 3 is a schematic plan view of a three-phase permanent magnet motor 20 having nine stator teeth 21,21 in three groups α, β and γ corresponding to the respective phases U, V and W of the three-phase power line and arranged in this order clockwise on the figure around the rotor 1, which is a diametrally oriented cylindrical permanent magnet having a direction of magnetic orientation indicated by the double-sided arrow and magnetized to have six magnetic poles in the manner illustrated in Figure 1A. The wirings to the stator teeth are wound around the stator teeth 21,21 and connected together to the respective phases of the power input line leading to the motor. When an electric current flows through the coils 22,22, a magnetic field is generated by the coils 22,22 so that the rotor 1 is rotated by means of the magnetic repulsion and attraction between the magnetic field generated by the coils 22,22 and the cylindrical permanent magnet 1. Each of U-V, V-W and W-U circumferentially covers one third of the overall stator teeth 21,21 and, when an electric current flows through U-V, a magnetic field is generated from α of the stator core. Similarly, a magnetic field is generated from β and from γ by means of V-W and W-U, respectively.

[0025] Figure 3 is depicted to show such a relative positions of the stator and the rotor that U-V (α) is positioned to face the respective centers of the magnetic poles B, D and F of the cylindrical magnet 1 producing a rotation torque by interacting with U-V (α). The magnetic poles B and F are each in the vicinity of the direction of the diametral orientation of the cylindrical magnet 1 indicated by the double-sided arrow so that the magnetic flux density is larger thereon than that on the magnetic pole D which is remote from the direction of the diametral orientation of the cylindrical magnet 1. Since the number of the stator teeth 21,21, i.e. nine, is 3/2 times of the number of the magnetic poles, i.e. six, in the rotor 1, however, the magnetic flux interlinking with the coils 22,22 of U-V (α) as the total contribution of the magnetic poles F, B and D is always equal to that of the magnetic poles E, A and C. This relationship is held also for V-W (β) and U-V (γ). This situation means that, when a permanent magnet rotor having k magnetic poles, k being six in this case, is combined with a stator having n stator teeth ($n = 3k \cdot n_0/2 = 9$, n_0 being a positive integer and one in this case), a motor free from unevenness of rotation torque can be obtained even when the rotor is formed from a diametrally oriented cylindrical permanent magnet of which the magnetic flux density on the surface is unavoidably uneven with a higher density in the vicinity of the direction of diametral magnetic orientation than in the direction perpendicular to the diametral magnetic orientation by virtue of mitigation in the unevenness of the magnetic flux density.

[0026] The above described advantage in the evenness of rotation torque of a three-phase permanent magnet motor can be obtained for any combination of a cylindrical permanent magnet of k-polar magnetization as the rotor and a stator provided that the number of the stator teeth n is equal to $3k \cdot n_0/2$. Thus, permanent magnet motors exhibiting excellent performance without unevenness in rotation torque can be manufactured at low costs by using an inexpensive diametrally oriented cylindrical permanent magnet suitable for mass production by using a vertical-field in-field molding press.

[0027] A diametrally oriented cylindrical permanent magnet magnetized in multipolar magnetization has low magnetizability and magnetic properties in the vicinity of each magnetic pole as compared with a multiradially anisotropic ring magnet to ensure smooth variation in the magnetic flux density between magnetic poles, so that the cogging torque of the motor is small. The cogging torque can be further decreased when the cylindrical permanent magnet is skew-magnetized or the stator has skewed stator teeth. The skew angle is preferably in the range from one tenth to two thirds of the angle spanned by a single magnetic pole of the cylindrical magnet, i.e. 360°/k. When the skew angle is too small, the cogging torque cannot be substantially decreased by the skew magnetization of the rotor magnet and, when the skew angle is too large, an undue decrease is resulted in the rotation torque of the motor.

[0028] In an alternative definition, the present invention provides a permanent magnet motor which comprises, as an assembly:

(a) a stator having a plurality of stator teeth; and
(b) a rotor coaxially inserted into the stator, which is a monolithic cylindrical permanent magnet having magnetic anisotropy in a single diametral direction perpendicular to the cylinder axis and magnetized to have a plurality of evenly disposed magnetic poles around the circumference of the cylinder,

in which the number of the magnetic poles k of the rotor is an even number not exceeding 100 and the number of the stator teeth n is equal to $3n_0$, n_0 being a positive integer not exceeding 33, with the proviso that k is not equal to n.

[0029] When a permanent magnet motor satisfies the above described requirements for the rotor and stator, a magnetic pole having a low magnetic flux density is combined in each of the phases with a magnetic pole having a high magnetic flux density resulting in a smooth distribution of the total magnetic flux as an average to ensure evenness in the rotation torque of the motor. Accordingly, high-performance synchronous permanent magnet motors with small torque ripples can be manufactured at low costs by using an inexpensive diametrally oriented cylindrical permanent magnet as the rotor.

[0030] It is also optional in this case that the diametrally oriented cylindrical permanent magnet as the rotor can be magnetized in skew magnetization and the stator has skewed stator teeth with a skew angle in the range from one tenth to two thirds of 360°/k, i.e. 360° divided by the number of the magnetic poles.

[0031] in connection with the secondary object of the invention, the present invention provides a rotor in a permanent magnet motor in the form of a composite cylindrical permanent magnet block having an increased height, which comprises at least one assembly of at least two or, preferably, two to ten cylindrical unit permanent magnets coaxially stacked one on the other each having magnetic anisotropy in a single diametral direction perpendicular to the cylinder axis, the composite cylindrical permanent magnet block being magnetized in multipolar magnetization to have a plurality of magnetic poles around the circumference of the cylindrical block.

[0032] In particular, the above defined composite cylindrical permanent magnet block having an increased height as a rotor in a permanent magnet motor is assembled in such a fashion that the direction of diametral magnetic orientation of a first cylindrical unit permanent magnet makes a rotational displacement angle, within a plane perpendicular to the cylinder axis, relative to the direction of diametral magnetic orientation of a second cylindrical unit permanent magnet adjacent to the first by an angle of 180° divided by the number of the cylindrical unit permanent magnets stacked together one on the other assuming that the cylindrical unit permanent magnets each have substantially the same axial dimension or height.

[0033] As is described above, the rotor in a permanent magnet motor provided by the invention to accomplish the secondary object of the invention is a composite cylindrical permanent magnet block which consists of an assembly of at least two cylindrical unit permanent magnets each having diametral orientation and coaxially stacked one on the other and is magnetized as a block in multipolar magnetization.

[0034] In the plurality of cylindrical unit permanent magnets coaxially stacked one on the other to form a composite magnet block, the relationship between the direction of diametral orientation and the direction of multipolar magnetization of a unit magnet can be different from that of the other unit magnets. Taking six-polar magnetization as an exemplary case, one of the unit magnets can be magnetized in such a fashion as is illustrated in Figure 1A, in which the direction of the diametral orientation in a unit magnet 1 indicated by the double-sided arrow coincides with the direction connecting a pair of oppositely facing magnetizer coils 12,12 of the magnetizer head 10. The distribution of magnetic flux density on the surface of the unit magnet 1 six-polar magnetized as illustrated in Figure 1A is graphically shown in Figure 2. On the other hand, another unit magnet 1 can be six-polar magnetized in such a direction as illustrated in Figure 1B in which the direction of diametral orientation of the magnet 1 is perpendicular to the direction connecting a pair of oppositely facing magnetizer coils 12,12 of the magnetizer head 10. In this case, the magnetic flux density is large on the magnetic poles A and D at or in the vicinity of the direction of diametral orientation of the magnet 1 while the magnetic flux density is small on the magnetic poles B, C, E and F remote from the direction of diametral orientation of the magnet 1 in Figure 1B.

[0035] When a diametrally oriented cylindrical permanent magnet is divided within a plane perpendicular to the cylinder axis into two equal unit magnets and they are coaxially stacked one on the other in such a disposition that the direction of diametral orientation in the second unit magnet makes a rotational displacement angle θ varied up to 90° relative to the direction of diametral orientation of the first unit magnet and the stack of the two unit magnets as a block is six-polar magnetized in such a disposition that the direction of the diametral orientation of the first unit magnet coincides with the direction connecting a pair of oppositely facing magnetizer coils as is illustrated in Figure 1A, the overall magnetic flux on the magnetic poles A and D is increased while the overall magnetic flux on the magnetic poles B, C, E and F is decreased as the angle θ of rotation between the two unit magnets is increased.

[0036] The above description suggests a possibility of obtaining a permanent magnet motor having improved evenness of rotation torque with decreased variation in the distribution of the magnetic flux density by using a composite cylindrical permanent magnet block as the rotor which comprises at least one assembly of two or more of cylindrical unit magnets obtained by dividing a diametrally oriented cylindrical permanent magnet block along the axial direction into a plurality of unit magnets to be coaxially stacked one on the other followed by multipolar magnetization as a block.

[0037] Namely, two or more of the above mentioned divided unit magnets are coaxially stacked together one on the other each with a specified rotational displacement angle θ relative to the other unit magnets so that the differences in the magnetic flux density between the direction of diametral orientation and the direction perpendicular to the direction of diametral orientation can be uniformized and the variation of the magnetic flux density can be decreased so much between the magnetic poles. When the number of the cylindrical unit permanent magnets is equal to p assuming that the respective unit magnets have the same axial dimension or height, the rotational displacement angle θ of a unit magnet should be 180°/p in order to,maximize the uniformizing effect on the distribution of the magnetic flux density.

[0038] Relative to the above mentioned requirement for the rotational displacement angle being equal to 180° divided by the number of the unit magnets stacked one on the other, it should be noted that the number p does not always mean the total number of the unit magnets. Namely, for example, a cylindrical magnet block consisting of six unit magnets as a total can be a coaxial tandem combination of two cylindrical base magnet blocks each consisting of three unit magnets, each cylindrical base magnet block consisting of three unit magnets and satisfying the requirement for

the rotational displacement angle mentioned above.

[0039] In order to accomplish allotment of the directions of diametral orientation to the magnetic poles as uniformly as possible, furthermore, it is preferable that the number of the stacked unit magnets is equal to one half of the number of magnetic poles formed by multipolar magnetization. When this requirement is satisfied, the portions of a relatively large magnetic flux in the directions of diametral orientation and the portions of a relatively small magnetic flux in the directions perpendicular to the direction of diametral orientation can be allotted uniformly to the respective magnetic poles and the overall magnetic fluxes on the respective magnetic poles after multipolar magnetization can be equalized provided that the rotational displacement angle θ of a unit magnet relative to the adjacent unit magnet is equal to 180° divided by the number of the unit magnets.

[0040] The number of magnetic poles k in the multipolar magnetization of the composite cylindrical permanent magnet block preferably should not exceed 50 because, when the number of the magnetic poles is too large, the span for each magnetic pole is necessarily so small that full magnetization of the composite magnet block can hardly be accomplished. Furthermore, the number of the cylindrical unit magnets p coaxially stacked together should not exceed 10 in consideration of the increase in the costs when the number of the unit magnets is too large.

[0041] It is of course optional in this composite cylindrical permanent magnet block consisting of a plurality of unit magnets that the multipolar magnetization is performed for skew magnetization and the permanent magnet motor having the composite cylindrical permanent magnet block as the rotor has a stator with skewed stator teeth to further decrease the inherently small cogging torque of the motor. The skew angle of the multipolar magnetization of the rotor magnet and the skew angle of the skewed stator teeth each should be in the range from one tneth to two thirds of 360° divided by the number of the magnetic poles k.

[0042] In the following, the present invention is described in more detail by way of Examples and Comparative Examples making further reference to the accompanying drawing, which, however, never limit the scope of the invention in any way.

Example 1.

[0043] A rare earth-based magnetic alloy in the form of an ingot, which had a chemical composition expressed by the composition formula $Nd_{30.0}Dy_{3.0}Fe_{62.0}Co_{3.0}B_{1.0}Al_{0.4}Cu_{0.4}Si_{0.2}$, the numerical figures giving the percentages by weight of the respective elements, was prepared by melting together, in a vacuum melting furnace, each a specified amount of a metallic or elementary form of neodymium, dysprosium, iron, cobalt, aluminum, silicon and copper each having a purity of 99.7% by weight and elementary boron having a purity of 99.5% by weight followed by casting the melt into a metal mold. The ingot obtained by cooling of the melt was first crushed in a jaw crusher and then finely pulverized in a jet mill with nitrogen gas as the jet gas into a powder of particles having an average particle diameter of 3.5 μm.

[0044] The magnet powder was compression-molded into a powder compact of a cylindrical form or ring under a molding pressure of 1.0 ton/cm^2 with application of a magnetic field of 12 kOe in the direction perpendicular to the direction of compression or, namely, to the axis of the cylindrical form. The powder compact thus obtained was subjected to a sintering heat treatment in an atmosphere of argon gas at a temperature of 1090°C for 1 hour and then to an aging treatment at a temperature of 580°C for 1 hour followed by a machining work to give a diametrally oriented sintered magnet body of a ring form having an outer diameter of 30 mm, inner diameter of 25 mm and height of 30 mm.

[0045] Separately, a reference magnet in the form of a cylindrical block was prepared from the same magnetic alloy powder as used above and under the same conditions for molding and heat treatments as in the preparation of the above obtained ring-formed magnet. This reference magnet had magnetic properties including Br of 13.0 kG, iHc of 15 kOe and (BH)max of 40 MGOe.

[0046] The diametrally oriented ring-formed permanent magnet prepared above was subjected to six-polar magnetization by using a magnetizer head in the manner illustrated in Figure 1A. A test three-phase permanent magnet motor was built, as is illustrated in Figure 3 by a schematic plan view, by inserting the six-polar magnetized ring-formed magnet 1 as the rotor into a stator 20 having the same height as the rotor 1 provided with nine stator teeth 21,21 and nine motor coils 22,22. A motor shaft 2 made of a ferromagnetic material was inserted into and fixed to the ring formed rotor 1. Each of the stator teeth was formed with 100 turns winding of a fine copper wire.

[0047] The magnetic flux density between the respective phases U, V and W was measured by using a magnetic flux meter. The values of magnetic flux with six peaks by one revolution of the rotor 1 are shown in Table 1 below.

Comparative Example 1.

[0048] The experimental procedure was substantially the same as in Example 1 described above except that the 100-turns winding of the fine copper wire was provided only in one of the nine stator teeth 21,21 of the stator 20. The values of the magnetic flux for the six peaks determined by the measurement with a flux meter are shown also in Table

1 below.

[0049] As is understood from the results shown in Table 1, the values of magnetic flux (absolute value) in Example 1 vary within a very narrow range of less than ± 1% while the largest value in Comparative Example 1 is about three times larger than the smallest value.

Table 1

		Magnetic flux, kMx					
		peak 1	peak 2	peak 3	peak 4	peak 5	peak 6
Example 1	U-V	-30.5	30.2	-30.4	30.6	-30.2	30.3
	V-W	-30.6	30.2	-30.4	30.5	-30.3	30.2
	W-U	30.2	-30.3	30.5	-30.3	30.3	-30.6
Comparative Example 1		12.8	-38.2	37.5	-13.4	38.0	-37.2

Example 2.

[0050] Measurements were made for the induced voltage when the rotor 1 of the test three-phase permanent magnet motor built in Example 1 was rotated at 1000 rpm and also for the torque ripples determined by using a load cell when the rotor 1 was rotated ar 1 to 5 rpm. The results were that the maximum value of the induced voltage was 50 volts and the difference between the largest and smallest values of torque ripples was 0.077 Nm indicating that this test motor was suitable for practical use in respects of the large induced voltage and small torque ripples.

Example 3.

[0051] A test three-phase permanent magnet motor was built in the same manner as in Example 1 except that the diametrally oriented cylindrical permanent magnet as the rotor 1 was six-polar skew-magnetized at a skew angle of 20° which was one third of the angle 60° spanned by a single magnetic pole. The maximum value of the induced voltage was 48 volts, which was comparable with the value 50 volts in Example 2, and the difference between the largest and smallest values of torque ripples was 0.021 Nm, which was much smaller than the value of 0.077 Nm in Example 2.

[0052] Figure 4 of the accompanying drawing shows the induced voltage as a function of the electrical angle by the three curves a, b and c for the U-V, V-W and W-U phases, respectively, in Figure 3. As is clear from Figure 4, the induced voltage exhibits a smooth and regular sine curve without unevenness or irregularity.

Example 4.

[0053] A test three-phase permanent magnet motor was built in the same manner as in Example 1 except that the diametrally oriented cylindrical permanent magnet as the rotor 1 was six-polar skew-magnetized at a skew angle of 50° which was five sixths of the angle 60° spanned by a single magnetic pole. The maximum value of the induced voltage was 7 volts but the difference between the largest and smallest values of torque ripples was 0.017 Nm, which was much smaller than the value in Example 2 by non-skewed multipolar magnetization.

Example 5.

[0054] A test three-phase permanent magnet motor was built in the same manner as in Example 1 except that the stator 20 had nine skewed stator teeth 21 at a skew angle of 20° which was one third of the angle 60° spanned by a single magnetic pole of the six-polar magnetized diametrally oriented permanent magnet 1 as the rotor. The maximum value of the induced voltage was 48 volts, which was comparable with the value of 50 volts in Example 2, and the difference between the largest and smallest values of torque ripples was 0.025 Nm, which was much smaller than the value of 0.077 Nm in Example 2 with non-skewed stator teeth.

Example 6.

[0055] A diametrally oriented cylindrical permanent magnet having the same dimensions as in Example 1 was prepared in just the same manner as in Example 1. This diametrally oriented cylindrical magnet 31 was magnetized in ten-polar magnetization and built, as is illustrated in Figure 5 by a schematic plan view, in a stator 30 having twelve

stator teeth 32 and twelve motor coils 33 each having 100-turns of copper wire winding to give a test three-phase permanent magnet motor.

[0056] Table 2 below shows the magnetic flux between the respective phases of U-V, V-W and W-U in this test motor determined by using a flux meter. As is understood from this table, the absolute values of the magnetic flux were in the range from 15.2 to 16.9 kMx with quite small variations and the variation in the magnetic flux among magnetic poles could be fully smoothened by building the rotor into a motor.

[0057] Measurements were made for the induced voltage when the rotor 31 of the test three-phase permanent magnet motor built above was rotated at 1000 rpm and also for the torque ripples determined by using a load cell when the rotor 31 was rotated ar 1 to 5 rpm. The results were that the maximum value of the induced voltage was 40 volts and the difference between the largest and smallest values of torque ripples was 0.080 Nm indicating that this test motor was suitable for practical use in respects of the large induced voltage and small torque ripples.

Table 2

	Magnetic flux, kMx				
	peak 1	peak 2	peak 3	peak 4	peak 5
U-V	16.5	-15.8	16.2	-16.6	15.7
V-W	15.6	-15.2	16.4	-16.5	15.3
W-U	16.2	-16.8	16.3	-15.3	16.3
	peak 6	peak 7	peak 8	peak 9	peak 10
U-V	-16.3	15.5	-15.4	16.3	-15.8
V-W	-15.4	16.4	-16.2	15.8	-16.7
W-U	-15.8	16.2	-16.2	16.0	-15.9

Example 7.

[0058] A test three-phase permanent magnet motor was built in the same manner as in Example 6 except that the diametrally oriented cylindrical permanent magnet as the rotor 31 was ten-polar skew-magnetized at a skew angle of 12° which was one third of the angle 36° spanned by a single magnetic pole. The maximum value of the induced voltage was 38 volts, which was about the same as the corresponding value in Example 6, and the difference between the largest and smallest values of torque ripples was 0.021 Nm, which was much smaller than the value of 0.080 Nm in Example 6 with non-skewed magnetic poles.

Example 8.

[0059] A test three-phase permanent magnet motor was built in the same manner as in Example 6 except that the stator 30 had twelve skewed stator teeth 32 at a skew angle of 12° which was one third of the angle 36° spanned by a single magnetic pole of the ten-polar magnetized diametrally oriented permanent magnet 31 as the rotor. The maximum value of the induced voltage was 38 volts, which was only slightly smaller than the value 40 volts in Example 6, and the difference between the largest and smallest values of torque ripples was 0.025 Nm, which was much smaller than the value of 0.080 Nm in Example 6 with non-skewed stator teeth.

Example 9.

[0060] A test three-phase permanent magnet motor was built in the same manner as in Example 6 except that the diametrally oriented cylindrical permanent magnet as the rotor 31 was ten-polar skew-magnetized at a skew angle of 30° which was five sixths of the angle 36° spanned by a single magnetic pole. The maximum value of the induced voltage was 7 volts but the difference between the largest and smallest values of torque ripples was 0.017 Nm, which was much smaller than the value 0.080 Nm in Example 6 by non-skew multipolar magnetization.

Comparative Example 2.

[0061] Two diametrally oriented cylindrical permanent magnets each having an outer diameter of 30 mm, inner diameter of 25 mm and height of 15 mm were prepared from the same rare earth magnetic alloy powder as used in Example 1 and in the same preparation procedures as in Example 1. These two diametrally oriented cylindrical unit

magnets were coaxially stacked one on the other in such a disposition that the directions of the diametral orientation of the two unit magnets made a rotational displacement angle of 60° within a plane perpendicular to the cylinder axis and the stack was subjected to six-polar magnetization as a block on a magnetizer head in such a manner that one of the unit magnets was positioned in a disposition relative to the magnetizer head as illustrated in Figure 1A.

[0062] The magnetic flux around the thus six-polar magnetized composite cylindrical magnet block as a stack of the two unit magnets was measured in the manner described below. Thus, a 10.5 mm by 30 mm rectangular coil with 50 turns of a fine copper wire winding was prepared and the coil was quickly moved from a position in direct contact with one of the magnetic poles of the composite magnet block to a sufficiently remote position going out of substantial reach of the magnetic field around the composite magnet block to determine the magnetic flux by using a flux meter. The six peak values of the magnetic flux are shown in Table 3 below for the respective magnetic poles. Example 10.

[0063] The experimental procedure was just the same as in Comparative Example 2 except that the two diametrally oriented cylindrical unit magnets were coaxially stacked one on the other to give a composite magnet block in such a disposition that the directions of the diametral orientation of the two unit magnets made a rotational displacement angle of 90° therebetween instead of 60° in Comparative Example 2.

[0064] The results of the magnetic flux measurement are shown also in Table 3.

Comparative Example 3.

[0065] The experimental procedure was just the same as in Comparative Example 2 except that the two diametrally oriented cylindrical unit magnets were coaxially stacked one on the other in such a disposition that the directions of the diametral orientation of the two unit magnets were along the same direction making no rotational displacement angle therebetween instead of 60° in Comparative Example 2.

[0066] The results of the magnetic flux measurement are shown also in Table 3.

Example 11.

[0067] The experimental procedure was about the same as in Comparative Example 2 except that each of the three diametrally oriented cylindrical unit permanent magnets had dimensions of an outer diameter of 30 mm, inner diameter of 25 mm and height of 10 mm instead of 15 mm in Comparative Example 2 and three, instead of two, unit magnets were coaxially stacked one on the other in such a disposition that the directions of the diametral orientation of the first and second unit magnets made a rotational displacement angle of 60° therebetween and the direction of diametral orientation of the third unit magnet made a rotational displacement angle of 60° with the second unit magnet and a rotational displacement angle of 120° with the first unit magnet therebetween.

[0068] Figure 6 of the accompanying drawing is a perspective view of the thus constructed three-stage composite cylindrical permanent magnet block consisting of three diametrally oriented cylindrical unit magnets 1A, 1B and 1C coaxially stacked one on the other and a motor shaft 2 and motor core 2A inserted into the center openings of the cylindrical unit magnets 1A, 1B and 1C. The bold arrows P, Q and R depicted as if to penetrate one of the unit magnets 1A, 1B and 1C, respectively, indicate the direction of diametral orientation of the respective unit magnets 1A, 1B and 1C.

[0069] The results of the magnetic flux measurement are shown also in Table 3 below.

Table 3

	Magnetic flux, kMx					
	peak 1	peak 2	peak 3	peak 4	peak 5	peak 6
Example 10	10.10	-8.72	10.02	-10.04	8.86	-10.20
Example 11	10.56	-10.62	10.52	-10.54	10.60	-10.56
Comparative Example 2	8.22	-8.10	11.99	-8.20	8.16	-12.12
Comparative Example 3	3.82	-12.26	12.44	-4.02	12.08	-11.90

Example 12.

[0070] A test three-phase permanent magnet motor was built in the same manner as in Example 3 except that the two-stage composite cylindrical permanent magnet block prepared in Example 10 was used as the rotor in place of the monolithick permanent magnet in Example 3 and that the number of turns of copper wire winding in each of the

stator teeth was 150 turns instead of 100 turns in Example 3. The stator had skewed stator teeth at a skew angle of 20° which was one third of the angle 60° spanned by a single magnetic pole.

[0071] Measurements were made for the induced voltage and the torque ripples in the same manner as in Example 2. The results were that the maximum value of the induced voltage was 78 volts and the maximum value of torque ripples was 0.028 Nm indicating that this test motor was suitable for practical use in respects of the large induced voltage and small torque ripples.

Example 13.

[0072] The experimental procedure was substantially the same as in Example 12 excepting for the use of the three-stage composite cylindrical permanent magnet block prepared in Example 11 as the rotor instead of the two-stage composite magnet block used in Example 12.

[0073] The results of the measurements were that the induced voltage was 85 volts and the maximum value of torque ripples was 0.021 Nm indicating still higher performance of the motor than that of Example 12.

[0074] Figure 7 is a graph showing the induced voltage in the three-phase permanent magnet motor built above rotating at 1000 rpm as a function of the electrical angle. The curves a, b and c show the induced voltage in the phases U-V, V-W and W-U, respectively. Each of these curves exhibits a regular sine curve indicating smoothness of rotation of the motor.

Comparative Example 4.

[0075] The experimental procedure was substantially the same as in Example 12 excepting for replacement of the two-stage composite cylindrical permanent magnet block used in Example 12 with a monolithic diametrally oriented cylindrical permanent magnet as the rotor.

[0076] The results of the measurements were that the induced voltage was 73 volts and the maximum value of torque ripples was 0.120 Nm indicating that this test motor was not suitable for practical use due to the unduly large torque ripples.

Comparative Example 5.

[0077] The experimental procedure was substantially the same as in Example 12 except that the skew angle of the six-polar skew-magnetized composite cylindrical permanent magnet block was 50°, which was five sixths of the angle 60° spanned by a single magnetic pole instead of 20° in Example 12.

[0078] The results of the measurements were that the induced voltage was only 13 volts and the maximum value of torque ripples was 0.015 Nm indicating that this test motor was not suitable for practical use due to the unduly small induced voltage.

Example 14.

[0079] Six diametrally oriented cylindrical unit permanent magnets 51A, 51B, 51C, 51D, 51E. 51F each having dimensions of an outer diameter of 25 mm, inner diameters of 20 mm and height of 15 mm were prepared from the same rare earth-based permanent magnet alloy powder prepared and used in Example 1 under the same preparation conditions as in Example 1. These unit magnets 51A to 51F were coaxially stacked one on the other to form a six-stage composite cylindrical magnet block 51 in such a disposition relative to the direction of the diametral orientation of the respective unit magnets, as is illustrated in Figure 8, which is a perspective view of a rotor consisting of the composite cylindrical magnet block 51 with insertion of the motor shaft 52 and motor core 52A, that the direction of diametral orientation in a unit magnet made a rotational displacement angle of 60° with the direction of diametral orientation of the adjacent unit magnet as is indicated by the bold arrow marks in Figure 8 as if to penetrate the respective unit magnets 51A to 51F.

[0080] It is noted that the above described six-stage composite cylindrical magnet block 51, in which the rotational displacement angle between adjacent unit magnets is 60° as is mentioned above, is equivalent to a tandem combination of two three-stage magnet blocks in each of which the rotational displacement angle between adjacent unit magnets is 120° which is one third of 360°.

[0081] The six-stage composite cylindrical permanent magnet block 51 prepared above was subjected to six-polar skew magnetization with a skew angle of 7°. A three-phase permanent magnet motor was built with the rotor consisting of the composite cylindrical magnet block 51 with insertion of the motor shaft 52 and motor core 52A and a stator having nine stator teeth.

[0082] The results of the measurements were that the induced voltage was 45 volts and the maximum value of torque

ripples was 0.013 Nm indicating that this test motor was suitable for practical use.

Comparative Example 6.

[0083] The experimental procedure was substantially the same as in Example 14 except that the six cylindrical unit magnets were coaxially stacked one on the other in such a disposition that the directions of diameteral orientation in the unit magnets were in one and the same direction making no rotational displacement angle between the directions of two adjacent unit magnets.

[0084] The results of the measurements were that the induced voltage was 40 volts but the maximum value of torque ripples was as large as 0.569 Nm indicating that this test motor was not suitable for practical use due to the unduly large torque ripples as compared with that in Example 13.

Claims

1. A permanent magnet motor which comprises, as an assembly:

   (a) a stator (20) having a plurality of stator teeth (21); and
   (b) a rotor (1) coaxially inserted into the stator (20), which is a cylindrical permanent magnet having magnetically anisotropic orientation in a single diametral direction perpendicular to the cylinder axis and magnetized to have a plurality of evenly disposed magnetic poles around the circumference of the cylinder in which the number of the magnetic poles k of the rotor is an even number not exceeding 100 and the number of the stator teeth n is equal to $3n_0$, n_0 being a positive integer not exceeding 33, with the proviso that k is not equal to n.

2. The permanent magnet motor as claimed in claim 1 in which the number of the magnetic poles k of the rotor (1) is an even number not smaller than 4 and the number of the stator teeth (21) n is equal to $3k\text{-}n_0/2$, n_0 being a positive integer.

3. The permanent magnet motor as claimed in claim 1 in which the diametrally oriented cylindrical permanent magnet as the rotor (1) is multipolar skew-magnetized to have a plurality of skewed magnetic poles, the skew angle of the skewed magnetic poles being in the range from one tenth to two thirds of 360°/k.

4. The permanent magnet motor as claimed in claim 1 in which the stator has a plurality of skewed stator teeth (21), the skew angle of the skewed stator teeth (21) being in the range from one tenth to two thirds of

5. A permanent magnet motor as claimed in any one of claims 1 to 4 in which to rotor (1) is in the form of a composite cylindrical permament magnet block, which comprises at least one assembly of at least two cylindrical unit permanent magnets coaxially stacked one on the other having an identical height and each having magnetic anisotropic orientation in a single diametral direction perpendicular to the cylinder axis, the composite cylindrical permanent magnet block being magnetized in multipolar magnetization to have a plurality of evenly disposed magnetic poles around the circumference of the cylindrical magnet block, and in which the direction of diametral orientation of a first cylindrical unit permanent magnet makes a rotational displacement angle within a place perpendicular to the cylinder axis relative to the direction of diametral orientation of a second cylindrical unit permanent magnet adjacent to the first cylindrical unit permanent magnet, the rotational displacement angle being equal to 180° divided by the number of the cylindrical unit permanent magnets coaxially stacked together on the other.

6. The permanent magnet mortor as claimed in claim 5 in which the number of the magnetic poles around the circumference of the composite cylindrical permanent magnet block as the rotor is an even number not exceeding 50 and the number of the cylindrical unit permanent magnets coaxially stacked together one on the other is equal to one half of the number of the magnetic poles.

7. The permanent magnet motor as claimed in claim 5 in which the composite cylindrical permanent magnet block as the rotor (1) is multipolar skew-magnetized to have a plurality of skewed magnetic poles around the circumference of the cylinder, the skew angle of the skewed magnetic poles being in the range from one tenth to two thirds of 360° divided by the number of the skewed magnetic poles.

Patentansprüche

1. Dauermagnetmotor der als einen Zusammenbau aufweist: (a) einen Stator (20) mit einer Mehrzahl von Statorzähnen (21) und (b) einen in den Stator (20) koaxial eingesetzten Rotor (1), der ein zylindrischer Dauermagnet mit einer Orientierung seiner magnetischen Anisotropie in einer einzigen diametralen Richtung senkrecht zur Zylinderachse und so magnetisiert ist, daß er eine Mehrzahl von gleichmäßig rings um den Umfang des Zylinders angeordneten Magnetpolen aufweist, wobei die Anzahl k der Magnetpole des Rotors eine gerade Zahl nicht größer als 100 und die Zahl n der Statorzähne gleich $3n_0$ ist, wobei n_0 eine positive Zahl nicht größer als 33 ist und k nicht gleich n ist.

2. Dauermagnetmotor nach Anspruch 1, worin die Zahl k der Magnetpole des Rotors (1) eine gerade Zahl nicht kleiner als 4 und die Zahl n der Statorzähne (21) gleich $3k-n_0/2$ ist, wobei n_0 eine positive Zahl ist.

3. Dauermagnetmotor nach Anspruch 1, worin der diametral orientierte zylindrische Dauermagnet als Rotor (1) mehrpolig schräg magnetisiert ist, so daß er eine Mehrzahl von schrägen magnetischen Polen hat, wobei der Schrägwinkel der schrägen magnetischen Pole im Bereich von einem Zehntel bis zwei Drittel von 360°/k liegt.

4. Dauermagnetmotor nach Anspruch 1, worin der Stator eine Mehrzahl von schrägen Statorzähnen (21) hat, wobei der Schrägwinkel der schrägen Statorzähne (21) im Bereich von einem Zehntel bis zwei Drittel von 360°/k liegt.

5. Dauermagnetmotor nach einem der Ansprüche 1 bis 4, worin der Rotor (1) die Form eines zusammengesetzten zylindrischen Dauermagnetblocks hat, der wenigstens einen Zusammenbau von wenigstens zwei zylindrischen Dauermagneteinheiten aufweist, die aufeinandergestapelt sind und eine identische Höhe und jede eine Orientierung der magnetischen Anisotropie in einer einzigen diametralen Richtung senkrecht zur Zylinderachse aufweisen, wobei der zusammengesetzte zylindrische Dauermagnetblock mit einer mehrpoligen Magnetisierung magnetisiert ist, so daß er eine Mehrzahl von gleichmäßig um den Umfang des zylindrischen Magnetblocks verteilten magnetischen Polen aufweist, wobei die Richtung der diametralen Orientierung einer ersten zylindrischen Dauermagneteinheit um einen Verdrehungswinkel in einer zur Zylinderachse -senkrechten Ebene bezüglich der Richtung der diametralen Orientierung einer zweiten zylindrischen Dauermagneteinheit gedreht ist, die der ersten zylindrischen Dauermagneteinheit benachbart ist, wobei Verdrehungswinkel gleich 180° geteilt durch die Anzahl der koaxial aufeinandergestapelten zylindrischen Dauermagneteinheiten ist.

6. Dauermagnetmotor nach Anspruch 5, worin die Anzahl der Magnetpole rings um den Umfang des zusammengesetzten zylindrischen Dauermagnetblocks als Rotor eine gerade Zahl nicht größer als 50 und die Anzahl der koaxial aufeinandergestapelten zylindrischen Dauermagneteinheiten gleich der Hälfte der Anzahl der Magnetpole ist.

7. Dauermagnetmotor nach Anspruch 5, worin der zusammengesetzte zylindrische Dauermagnetblock als Rotor (1) mehrpolig schräg magnetisiert ist, so daß er eine Mehrzahl von schrägen Magnetpolen rings um den Umfang des Zylinders hat, wobei der Schrägwinkel der schrägen Magnetpole im Bereich von einem Zehntel bis zwei Drittel von 360° geteilt durch die Anzahl der schrägen Magnetpole ist.

Revendications

1. Moteur à aimant permanent qui comprend, sous forme d'assemblage : (a) un stator (20) ayant une pluralité de dents de stator (21) et (b) un rotor (1) inséré coaxialement dans le stator (20), qui est un aimant permanent cylindrique ayant une orientation magnétique anisotropique dans une seule direction diamétrale perpendiculaire à l'axe du cylindre et magnétisé pour avoir une pluralité de pôles magnétiques disposés équitablement autour de la circonférence du cylindre, dans lequel le nombre de pôles magnétiques k du rotor est un nombre pair ne dépassant pas 100 et le nombre de dents du stator n est égal à $3n_0$, n_0 étant un nombre entier positif ne dépassant pas 33, à condition que k ne soit pas égal à n.

2. Moteur à aimant permanent selon la revendication 1 dans lequel le nombre de pôles magnétiques k du rotor (1) est un nombre pair pas inférieur à 4 et le nombre de dents du stator (21) n est égal à $3k-n_0/2$, n_0 étant un nombre entier positif.

3. Moteur à aimant permanent selon la revendication 1 dans lequel l'aimant permanent cylindrique orienté diamétralement en tant que rotor (1) est à magnétisation multipolaire décalée angulairement pour avoir une pluralité de

pôles magnétiques décalés, l'angle de décalage des pôles magnétiques décalés se situant dans la gamme allant d'une dent à deux tiers de 360°/k.

4. Moteur à aimant permanent selon la revendication 1, dans lequel le stator possède une pluralité de dents de stator décalés angulairement (21), l'angle de décalage des dents de stator décalées (21) se situe dans la gamme allant d'une dent à deux tiers de 360°/k.

5. Moteur à aimant permanent selon l'une quelconque des revendications 1 à 4 dans lequel le rotor (1) se trouve sous la forme d'un bloc d'aimants cylindrique composite, qui comprend au moins un assemblage d'au moins deux aimants permanents unitaires cylindrique empilés coaxialement les uns sur les autres ayant une hauteur identique et ayant chacun une orientation anisotropique magnétique dans une seule direction diamétrale perpendiculaire à l'axe du cylindre, le bloc d'aimants permanent cylindrique composite étant magnétisé dans une magnétisation multipolaire pour avoir une pluralité de pôles magnétiques disposés de manière égale autour de la circonférence du bloc d'aimants cylindrique, et dans lequel la direction de l'orientation diamétrale d'une premier aimant permanent unitaire cylindrique forme un décalage angulaire dans un plan perpendiculaire à l'axe du cylindre, par rapport à la direction de l'orientation diamétrale d'un deuxième aimant permanent unitaire cylindrique adjacent au premier aimant permanent unitaire cylindrique, le décalage angulaire étant égal à 180° divisé par le nombre d'aimants permanents unitaires cylindrique empilés coaxialement ensemble les uns sur les autres.

6. Moteur à aimant permanent selon la revendication 5 dans lequel le nombre de pôles magnétiques autour de la circonférence du bloc d'aimants permanent cylindrique en tant que rotor est un nombre pair ne dépassant pas 50 et le nombre d'aimants permanents unitaires cylindriques empilés coaxialement ensemble les uns sur les autres est égale à la moitié du nombre des pôles magnétiques.

7. Moteur à aimant permanent selon la revendication 5 dans lequel le bloc d'aimants permanents cylindrique composite en tant que rotor (1) est à magnétisation multipolaire décalée angulairement pour avoir une pluralité de pôles magnétiques décalés autour de la circonférence du cylindre, l'angle de décalage des pôles magnétiques décalés se situe dans la gamme allant d'un dixième à deux tiers de 360° divisé par le nombre de pôles magnétiques décalés.

FIG. 1A
PRIOR ART

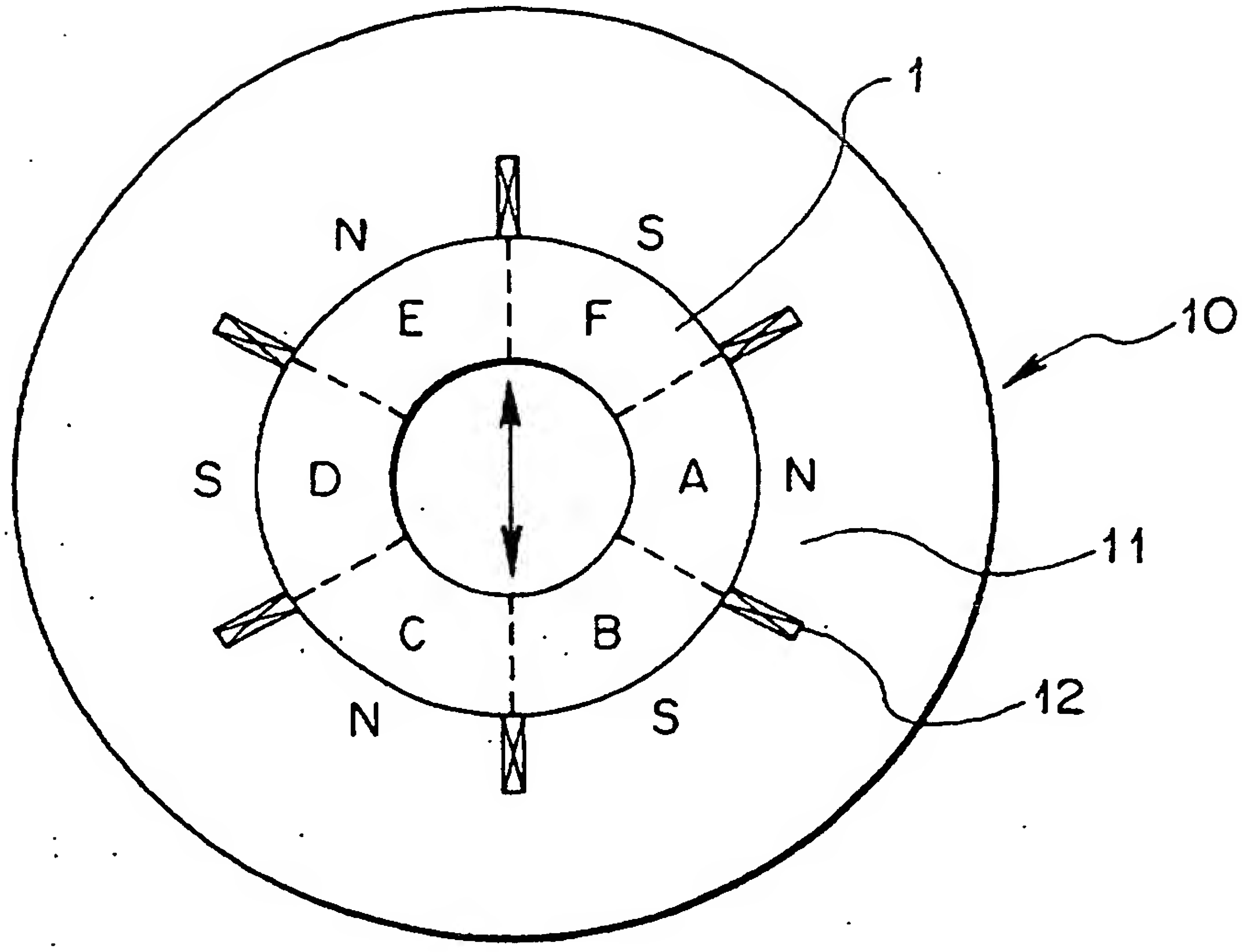

FIG. 1B
PRIOR ART

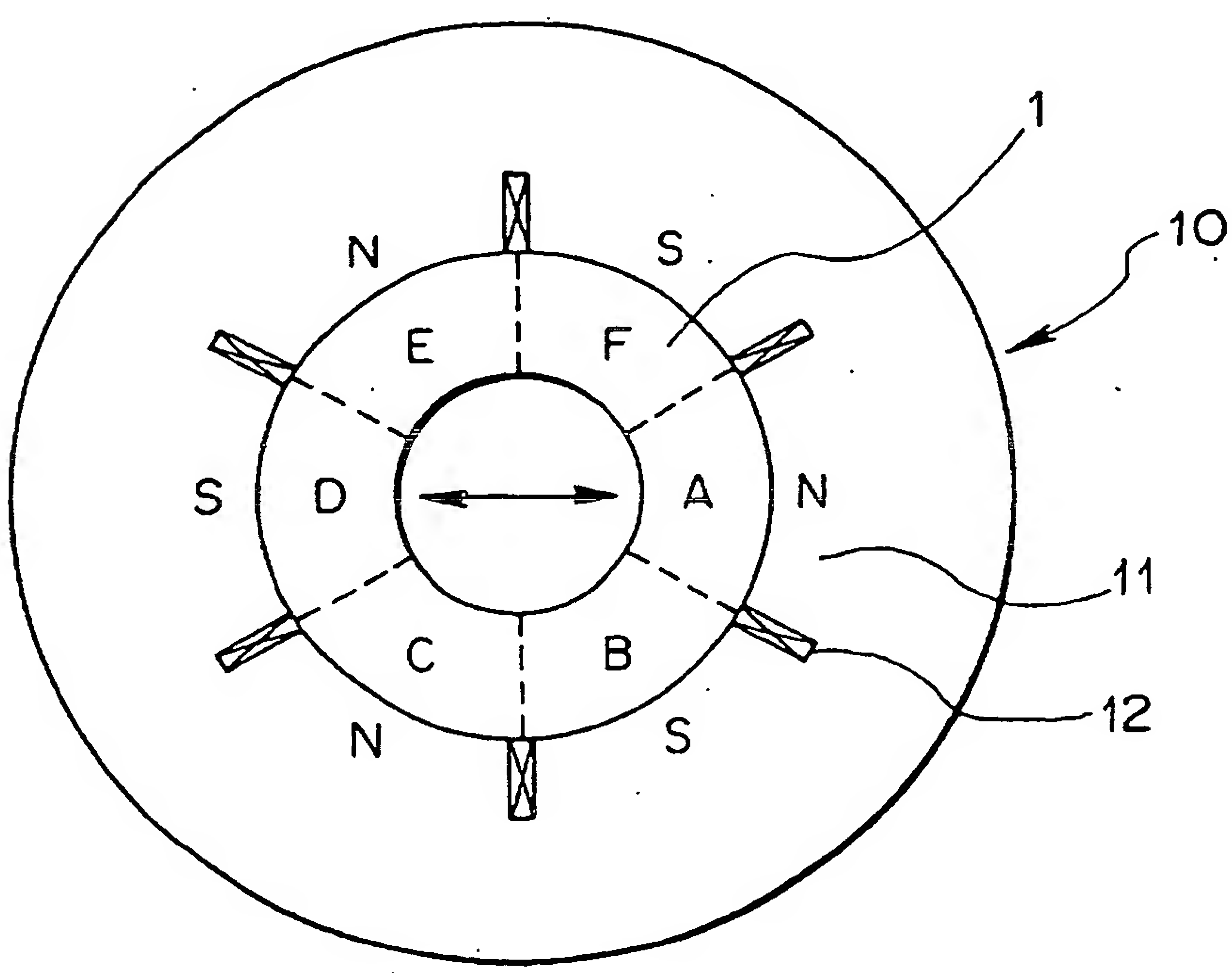

FIG.2
PRIOR ART

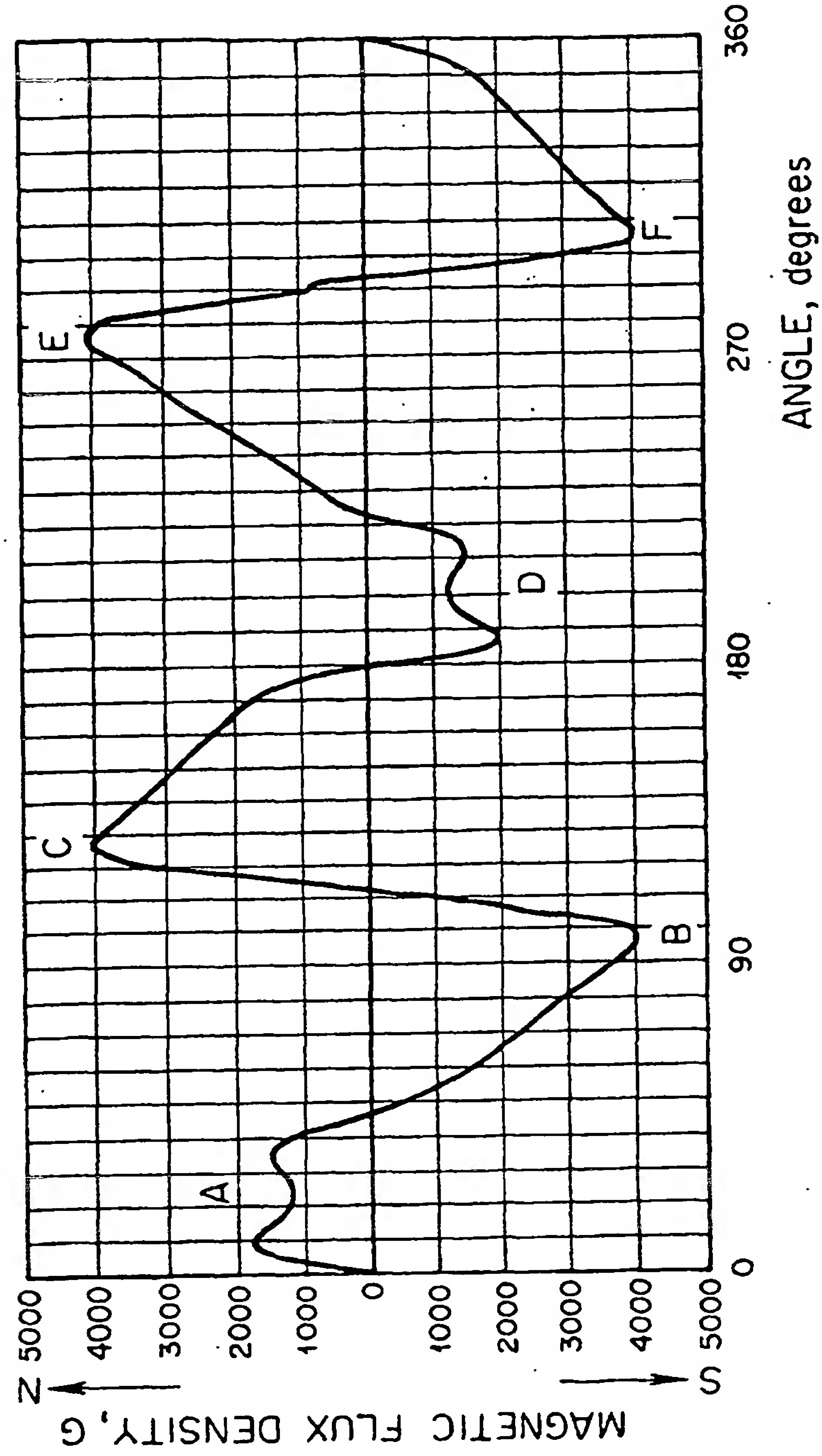

FIG.3

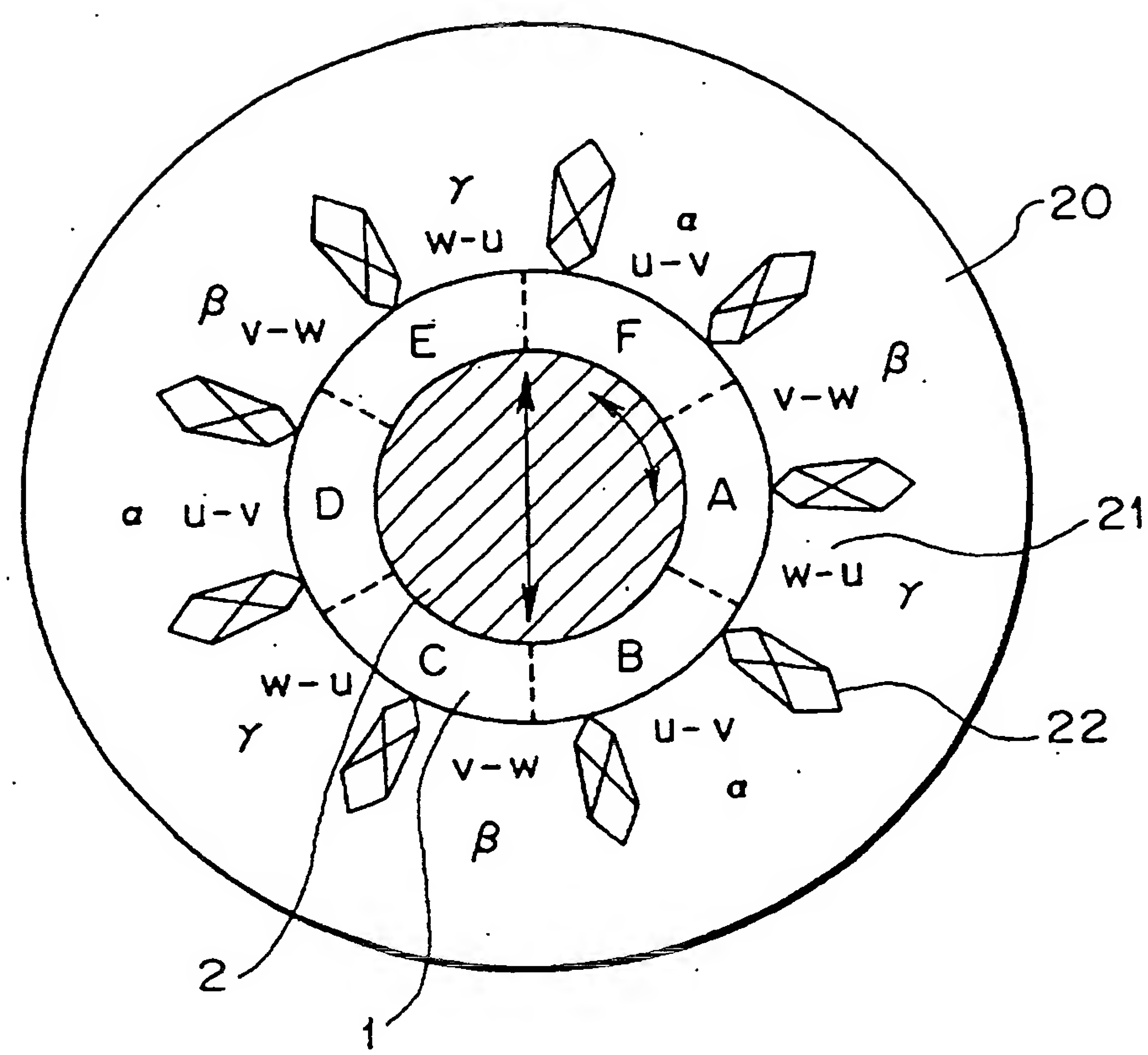

FIG.4

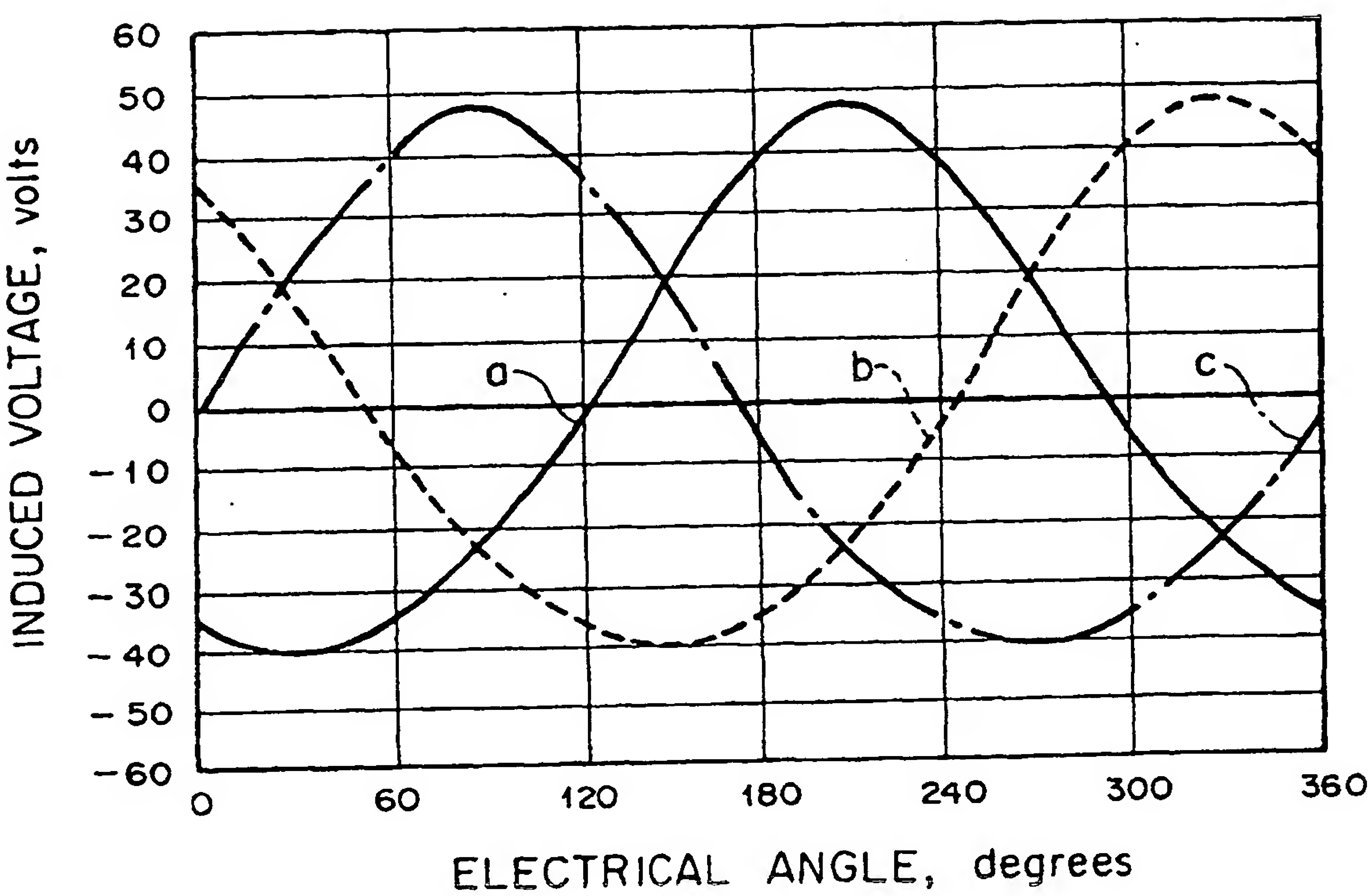
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
INDUCED VOLTAGE, volts
0
60
120
180
240
300
360
ELECTRICAL ANGLE, degrees
a
b
c

FIG. 5

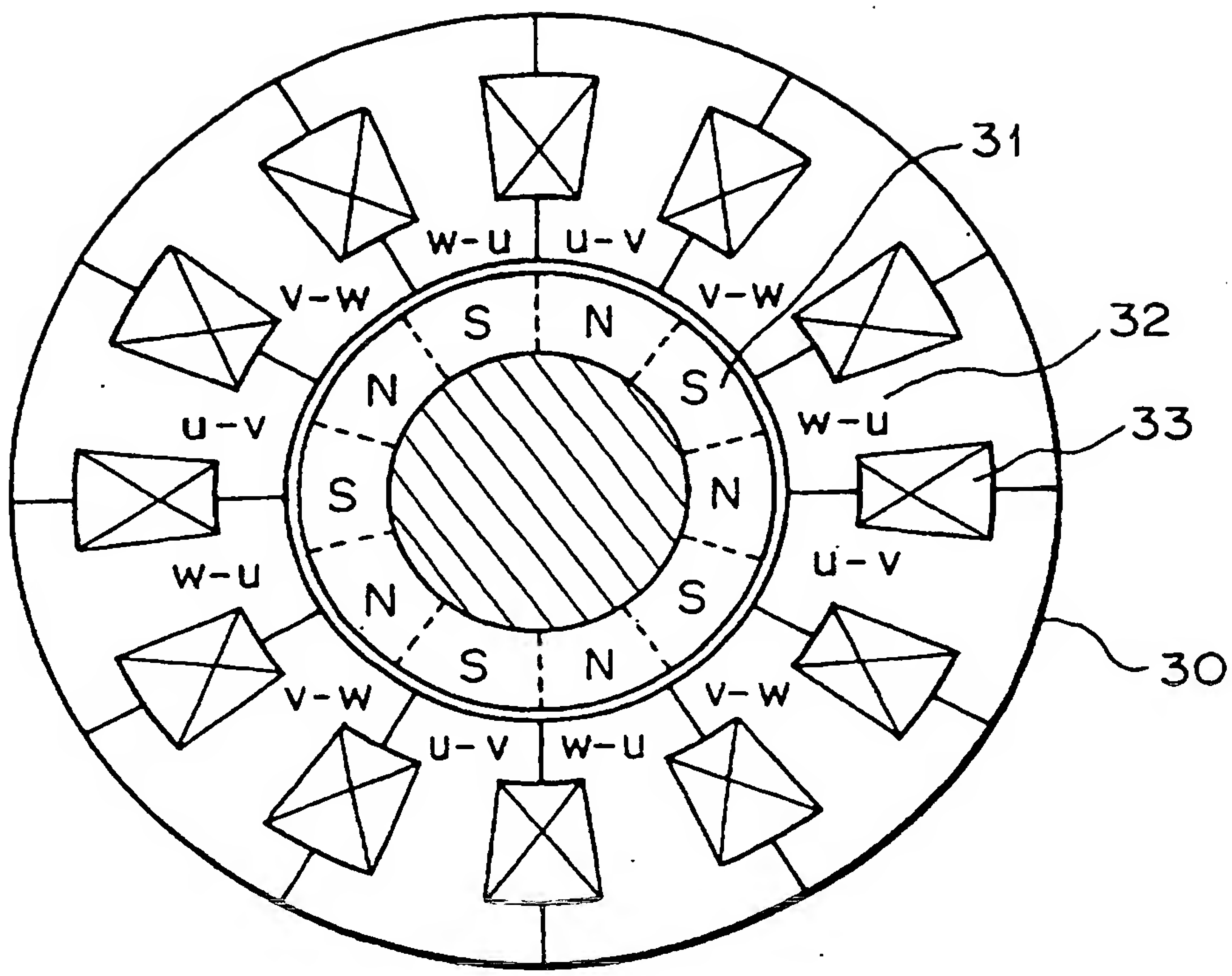

FIG.6

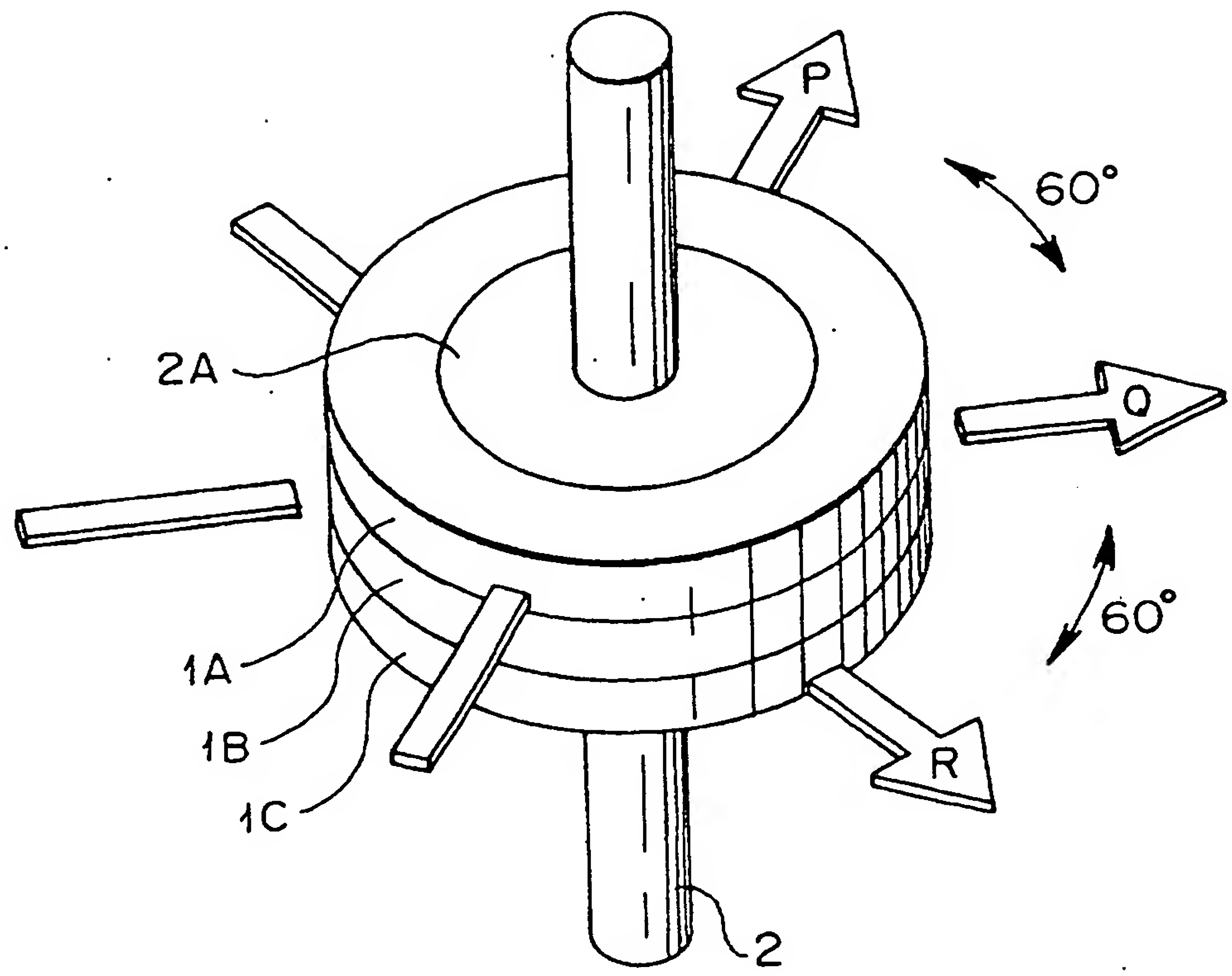

FIG.7

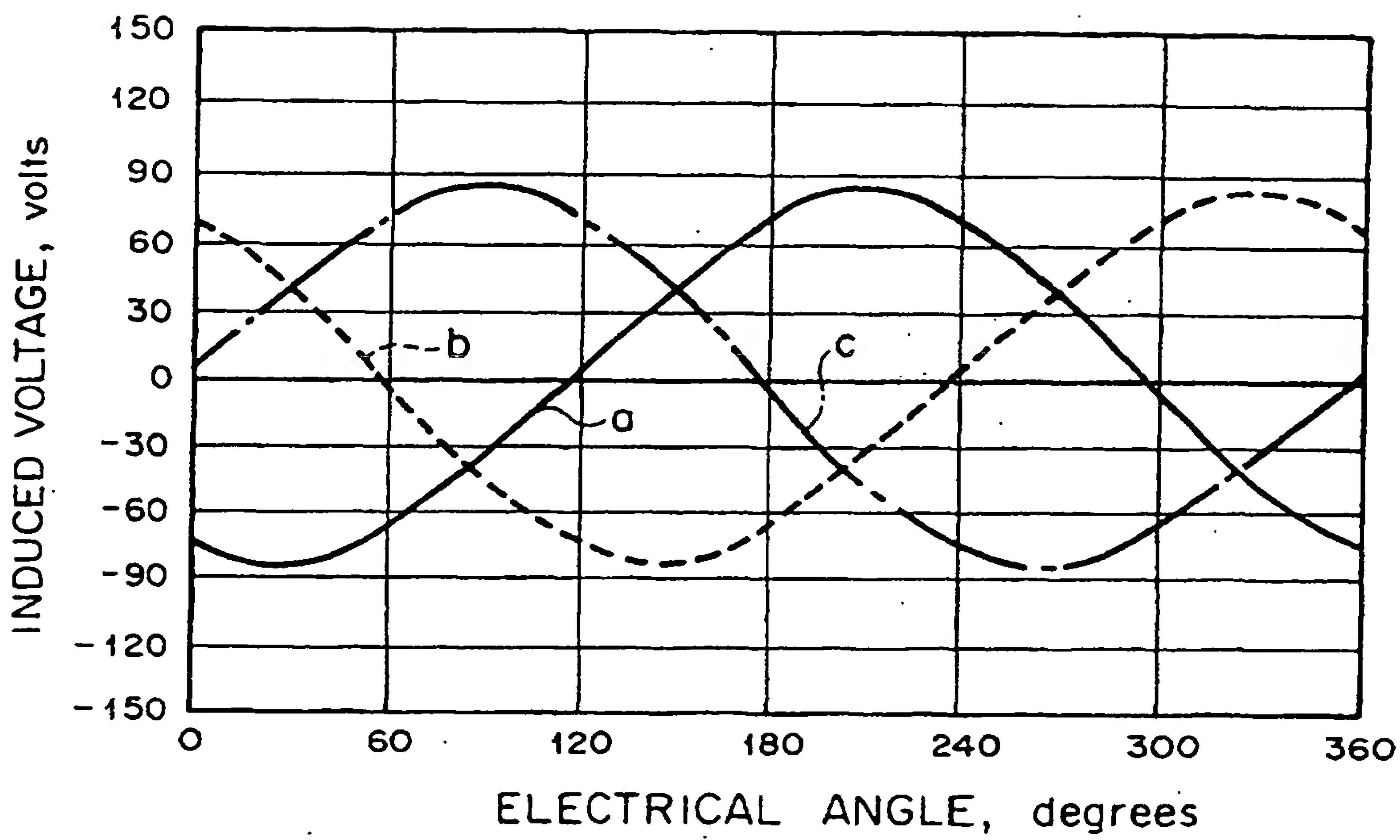
150
120
90
60
30
0
-30
-60
-90
-120
-150
INDUCED VOLTAGE, volts
0
60
120
180
240
300
360
ELECTRICAL ANGLE, degrees
a
b
c

FIG.8